# Magnetic response of the human visual motion area to coherent and incoherent motion

K. Lam[1], Y. Kaneoke[1], A. Gunji[1], H. Yamasaki[1], E. Matsumoto[2], T. Naito[3], and R. Kakigi[1]

*[1]Department of Integrative Physiology, National Institute for Physiological Sciences, Okazaki 444-8585;*
*[2]Graduate School of Human Environmental Studies and [3]Graduate School of Letters, Kyoto University,*
*Kyoto 606-8501, Japan*

## 1 Introduction

Humans perceive the overall direction of motion made up of numerous randomly moving elements. Random dot kinematograms (RDK) have been used in human and monkey experiments to determine what mechanism underlies the detection of such global motion. One of the most striking findings is that humans and monkeys can detect the direction in which only a few percent of the dots are moving coherently, remaining ones moving incoherently. To detect such coherent dot motion in the background of incoherently moving dots, each dot's motion must first be detected locally then integrated in a large spatial scale. This integration may occur in the extrastriate cortex because MT/V5 in the monkey is reported to be specifically related to the motion process, and the neurons' receptive fields are larger than those in the primary visual cortex (V1).

Recent positron emission tomography (PET) studies [3] showed that the same cortical regions, V1, the secondary visual cortex (V2) and V5, were similarly activated to both coherent and incoherent motions. This apparently contradicts the idea that neurons in V5 are heavily involved in the detection of coherent rather than incoherent motion.

In a previous magnetoencephalography (MEG) study, we found that random dot motion evoked magnetic responses from the human extrastriate cortex [1]. This motivated us to investigate the responses to both coherent and incoherent motions, using MEG which may elucidate the different properties of responses from the extrastriate cortex. This study was published in Neuroscience [2] and we summarized it in this paper.

## 2 Methods

Five healthy right-handed colleagues participated in this study. We used a RDK for the visual stimuli. It consisted of bright square dots (0.2x0.2°, 224 cd $m^{-2}$) randomly plotted on a dark background (10x10°, 4.3 cd $m^{-2}$). The dot density was 10%. Two visual scenes (VS1 and VS2) created by RDK were presented alternately to the left visual field at randomly varied presentation times (2 to 3 s at steps of 0.2 s) (Figs. 1 and 2). They produced two events in one MEG acquisition; stimulus change from VS1 to VS2 and from VS2 to VS1. Two types of dot motions, coherent (C) and incoherent (I) motion were used with the speed of 0, 0.6, 9.6, and $25°s^{-1}$ as indicated in the parentheses in figures. Stimulus with a dot speed of 0 is referred to as S (Stationary). We recorded the magnetic responses to stimuli from the right occipito-parieto-temporal region of the subject's brain, using a 37-channel neuromagnetometer (Magnes, BTi). Each subject lay on his/her right side on a bed in a dark magnetically shielded room and gazed at the fixation point on the screen. The viewing distance was 150 cm. MEG data 50 ms before and 700 ms after each event were amplified in the frequency range from 0.1 to 800 and digitized at 2083.3 Hz until 125 epochs were obtained. The data then were bandpass filtered at 1.0 to 80 Hz. The baseline level offset for each MEG channel was corrected to the mean value of the 50 ms data before the event. In order to reject artifacts related to eye movements, electrooculogram was recorded simultaneously.

The first component of the magnetic response was determined to be the first RMS deflection, the amplitude of which was more than 40 fT. Its peak latency and amplitude were measured as root mean square (RMS) values across the 37 channels of averaged MEG data. We used the single equivalent current dipole (ECD) model to estimate the location of the cortical activities and the strength of the current (dipole moment). The location then was superimposed on the magnetic resonance images (MRIs) for the anatomical investigation.

The experiment consisted of two sessions. Responses to the onset and offset of coherent (or incoherent) motion were evoked by the stimulus change between S and C (or S and I) at three different speeds of C (or I). Six MEG acquisitions therefore were required to obtain 12 magnetic responses.

In the second session, two types of motion (I and C) at three different speeds for each type were alternately presented, nine (3x3) MEG acquisitions giving 18 responses being obtained for each subject. The actual order of the stimuli used for each subject was randomized.

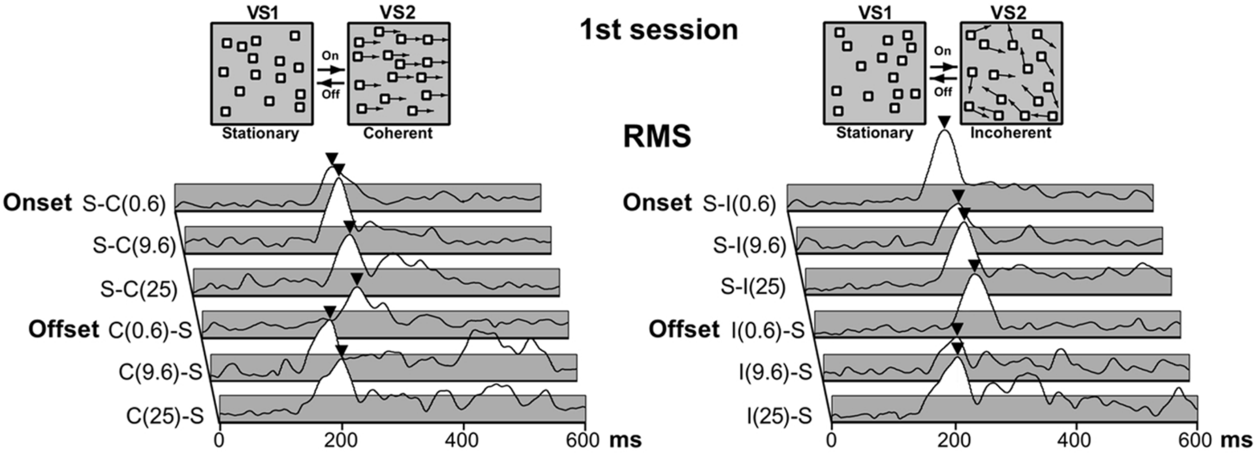

Figure 1: *Time course of the RMS values of the magnetic responses to the onset (S-C) (S-I) and offset (C-S) (I-S) of coherent and incoherent motion for one subject (S10). There was no latency change in the onset responses but the peak latency for the higher speed (9.6 and 25°$s^{-1}$) of the motion offset was shorter than the other latencies. Shaded areas on the RMS data represent the range of 0 to 40 fT.*

An analysis of Variance (ANOVA) was used for the statistical evaluation. P values less than 0.05 were considered significant in all the analyses.

## 3 Results

All the subjects had generally good MEG responses to the visual stimuli. The magnetic responses were composed of one to four components. We concentrated only on the first components because they had relatively large amplitudes and were easily distinguished.

### 3.1 Latency change in response to onset and offset of motion

Figure 1 shows the RMS values of the magnetic responses for both onset and offset of coherent and incoherent dot motion from a single subject (S10) in the first session. The onset response latencies were about 255 ms. In motion offset, the peak latencies of the first components for the higher speed (9.6 and 25°$s^{-1}$) were about 50 ms shorter than the latency for the lowest speed (0.6°$s^{-1}$) which was the same as that for the onset response. Waveforms of the responses to the onset and offset of incoherent motions were essentially the same as those for the coherent motions. Latency changes in the first component of the coherent motion offset response also were the same as those for incoherent motion offset responses.

Effects of subject and motion speed on the response latencies were assessed by a two-factor ANOVA. Speed had significant effect ($p<0.05$) on latencies in the responses to the offset of both coherent and incoherent motions.

### 3.2 Latency change in response to motion type change

Figure 2 shows the time course of the RMS values for responses to motion type changes in the second session. Peak latencies of the first components for the lowest speed (0.6°$s^{-1}$) of the preceding motion (about 260 ms for both motion changes) are 50 to 70 ms longer than the others, but the speed of the subsequent motion did not affect the latencies in either motion type change.

This tendency held for all the subjects. The significant effect ($p<0.001$) of preceding motion on latency was found by a three-factor ANOVA for each motion type change. There was a similar tendency for responses to the onset and offset of motion, because the speed of the preceding motion for motion onset is zero. Latencies were inversely related to the preceding speed ($p<0.001$), and response latencies for the preceding incoherent motions were significantly ($p<0.01$) longer (about 18 ms in mean) than those for the coherent motions by a three-factor ANOVA.

### 3.3 RMS amplitude and ECD moment of the magnetic response

In both sessions, there were no statistically significant differences for either the peak RMS amplitudes of the first components and their ECD moments value under the stimulus conditions used ($p>0.05$, two-factor ANOVA).

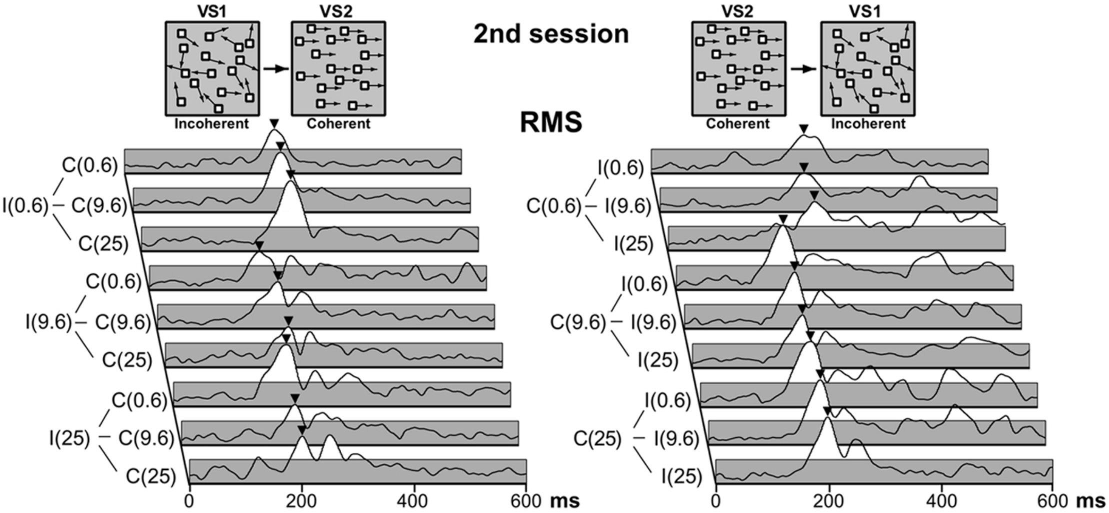

Figure 2: *Time course of RMS values of magnetic responses recorded from a single subject (S10) in the second session. The peak latencies at the lowest speed ($0.6°s^{-1}$) of preceding motion were longer than at the other speeds, and the speed of subsequent motion did not affect the latencies in either motion type change.*

### 3.4 Estimated origins of the magnetic responses

Thirty magnetic responses were collected for each subject in both experimental sessions. Origins of 30, 16, 18, 20 and 29 responses were successfully estimated for the subjects respectively of S10, S19, S29, S40 and S52 and their mean location was in the occipito-parieto-temporal region (Fig. 3). The value of Y (dorsolateral axis) is related to the preceding speed ($p<0.005$, three-factor ANOVA); i.e., the origin of the response to the slower preceding motion was lateral to that for the faster one. There was no significant change in the X (anteroposterior axis) and Z (dorsoventral axis) values with the preceding speed and no effect of motion type on any value. ECD moment did not change with preceding speed by two-factor ANOVA, while RMS value was inversely related to the preceding speed ($p<0.05$).

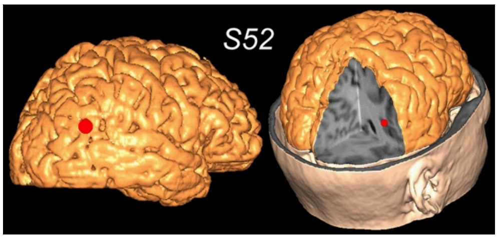

Figure 3: *Three-dimensional MRI of the human brain for a subject (S52) shows the center of the cortical area (red spot) responding to both coherent and incoherent motions. This area corresponds to the human presumptive MT/V5.*

## 4 Discussion

### 4.1 Response latency change with preceding motion speed

The mean response latencies changed about 100 ms with the preceding motion speed for both motion types, indicative that neural activities related to the speed of incoherent motion and coherent motion exist in the same extrastriate cortex. That region, however, may be less sensitive to the speed of incoherent motion because the response latencies for the incoherent motions were significantly longer (mean: 18 ms) than those for the coherent motions.

The neural process related to the response latency changes for preceding motion speeds is not known. Amplitude of the early phasic response of the monkey MST neurons are reported to be related to the response of preceding motion stimuli, but no response latency change was found. Although the origins of the responses varied with the speed of the preceding motion, a few centimeters' difference in the origin of the response does not seem to be sufficient to explain the 100 ms latency difference. Possibly the preceding motion depolarizes the neurons involved in the detection of subsequent motion by the mechanism of disinhibition, resulting in the increase of neural response sensitivity. Another possibility is that the first response to motion type change was related merely to the offset of the preceding motion. If so, the results suggest that the offset of the preceding incoherent or coherent motion is analyzed by a neural process independent of the one for the onset of the subsequent coherent or incoherent motion. The fact that the response latencies for the onset of motions did not change as much at subsequent motion speeds as those for the offset also suggests that the underlying neural process for the onset responses differ from that for the offset ones.

### 4.2 Estimated origins of the responses

The origins of the magnetic responses for each subject were estimated to be within the extrastriate cortex and corresponded to the presumptive human MT/V5. But whether the area has the same physiological properties as monkey MT/V5 is unknown. One of the most interesting results in this study is that the origins of the responses varied with the preceding motion speed and correlated with the latency changes. The origin of the response to a slower speed was lateral to that for a faster speed may indicate that the human presumptive MT/V5 is retinotopically organized with the laterally localized central visual field as in the monkey [4].

### 4.3 Possible neural activities related to the response to incoherent motion

Our findings show a marked similarity in the response properties of coherent and incoherent motions in terms of the amplitude, the latency change, and the estimated origin. This suggests that both coherent and incoherent motions are processed by the same neural populations. Many direction-selective neurons in the monkey MT and some neurons in the dorsomedial part of the medial superior temporal area (MSTd), however, respond to dynamic random dot noise (similar to our incoherent motion stimulus). Although the magnitudes of the neural responses to incoherent motion were much smaller that those for coherent motion, the former would activate most neurons, whereas in the same neural population for a given speed coherent motion would activate only that fraction of neurons which prefer that direction. This would result in the same response amplitudes and the estimated origins for both motions, as found in our present study.

Incoherent motion has been used as a noise stimulus to the visual system, and the response has been compared with responses to other coherent motion stimuli. Indeed, the response to incoherent motion does not seem to be necessary for the detection of motion; rather it would worsen the speed and direction tuning of the neurons because suppression in the anti-preferred direction is a key mechanism of such tunings. It is also possible, however, that the visual system utilizes such a response to detect incoherent motion, because the differences in the neural activity (distribution and magnitude) between coherent and incoherent motion would easily be detected by the other visual area. The existence of a neural mechanism to detect incoherent motion can itself enhance the detectability of the coherent dot motion from the "noisy" background of incoherently moving dots. This is because the contrast between the images of coherent and incoherent motion increases if the incoherent dot motion in an entire visual scene is perceived as a homogeneous background scene of incoherent motion. This may be the similar to the case of two different coherent dot motions in the same area of a visual scene. Certainly our visual system can handle such dots' motions to be perceived as coherent motions with two different directions. This perception is called motion transparency and neurons in the monkey MT have been known to be related to it. It also is dependent on the degree of unbalanced motion signals in a local area. Coherent motion therefore can be transparent in randomly moving dots (incoherent motion) only if incoherent motion, as well as coherent motion, is perceived as a homogeneous visual motion scene, because both motions are highly unbalanced.

### Acknowledgements

This study was supported by the Ministry of Education, Science, Sports, and Culture, Japan. We thank Mr. O. Nagata, Mr. Y. Takeshima for their technical assistance and Dr. H. Komatsu and Dr. A. Hanazawa their valuable comments.

### References

1. Y. Kaneoke, M. Bundou, S. Koyama, H. Suzuki, and R. Kakigi, "Human cortical area responding to stimuli in apparent motion", *Neuroreport* **8**, 677-682, 1997.
2. K. Lam , Y. Kaneoke, A. Gunji, H. Yamasaki, E. Matsumoto, T. Naito, and R. Kakigi, "Magnetic response of human extrastriate cortex in the detection of coherent and incoherent motion", *Neuroscience* **97**, 1-10, 2000.
3. D.J. McKeefry, J.D.G. Watson, R.S. Frackowiak, K. Fong, and S. Zeki, "The activity in human areas V1/V2, V3, and V5 during the perception of coherent and incoherent motion", *Neuroimage* **5**, 1-12, 1997.
4. M.I. Sereno, C.T. McDonald, and J.M. Allman, "Analysis of retinotopic maps in extrastriate cortex", *Cereb Cortex* **6**, 601-620, 1994.